2 Peat Soils

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2.1 Introduction

Peat Soils cover 4.3% of Wales, and support nationally and internationally rare bog and fen habitats. In the uplands, blanket bogs form in waterlogged conditions, and contain peat-forming plant species such as *Sphagnum* mosses, as well as characteristic species such as heather and cotton grasses, and rare species such as sundews and cloudberries. In addition to their importance for biodiversity, Peat Soils act as Wales' largest terrestrial ecosystem store of carbon, and in good condition have the potential to contribute to climate regulation through ongoing CO_2 sequestration. However, Welsh Peat Soils have been detrimentally impacted by centuries of human activity including drainage, over-grazing and conversion to grassland and forestry. As a result Welsh Peat Soils are currently thought to act as a source of greenhouse gas (GHG) emissions. Options supported through Glastir aim to reduce these emissions, and to restore the carbon sequestration function of Welsh Peat Soils, through a reduction in land-use pressures on a range of both upland and lowland bogs and fens.

In year 2 of the GMEP project we have focused on two main activities. The first of these has involved a major new assessment of the extent and condition of the Welsh peat resource. Identifying the extent and location of peat is important in order to quantify the area of different habitats that Peat Soils support, the amount of carbon they store, and the land-use pressures they are likely to be subject to. An improved knowledge of the condition of this Peat Soil area subsequently enables us to identify the potential effects of land-use on Peat Soil ecosystem functions such as carbon sequestration, greenhouse gas emissions, provision of drinking water and regulation of flooding. From this information, it should be possible to target Glastir options and resources more effectively in order to provide the maximum benefit for Peat Soil habitats, for their climate and water regulation functions, and for the people who benefit from these ecosystem services.

The second task undertaken for Peat Soils during Year 2 of GMEP has involved the measurement of long-term carbon accumulation rates at a range of blanket bogs across Wales, using dated peat cores. This ongoing work aims to quantify how changes in land-management and resulting vegetation have affected rates of historical peat growth, which should provide an improved understanding of how these activities influence the rate of carbon accumulation in blanket bogs today. By quantifying these relationships, the aim of the work is to develop new monitoring methods whereby data collected in the annual GMEP vegetation surveys can be used to provide a 'proxy' measure of carbon accumulation rate, allowing the carbon benefits of Glastir options on blanket bog to be more effectively monitored and evaluated in future.

2.2 Highlights and key findings

In year 1 of GMEP in addition to the core survey activities, work undertaken included the mapping of the extent of peat erosion across Wales from aerial photographs, and an assessment of whether satellite data could be used to monitor changes in the surface elevation of Peat Soils that would indicate whether they were accumulating or losing carbon. In Year 2, we have undertaken a detailed new assessment of the extent and condition of the full Welsh Peat Soil resource, based on an integrated analysis of soil mapping data, land-cover data and the use of aerial photographs to identify and map drainage ditches. We have also collected a large number of peat cores, which are being used to measure rates of peat accumulation over the last century as a function of land-use.

2.2.1 Key results from Year 2 include:

- A new unified peat map has been defined for the GMEP project which should allow a more reliable assessment of the state of the Welsh peat resource as a whole, with better representation of lowland peats, and more accurate targeting of Glastir peat soil-related options on those areas where peats are present (Figure 17).

- This map has now been passed to Glastir Contract Managers to use when negotiating new Glastir Agreements.

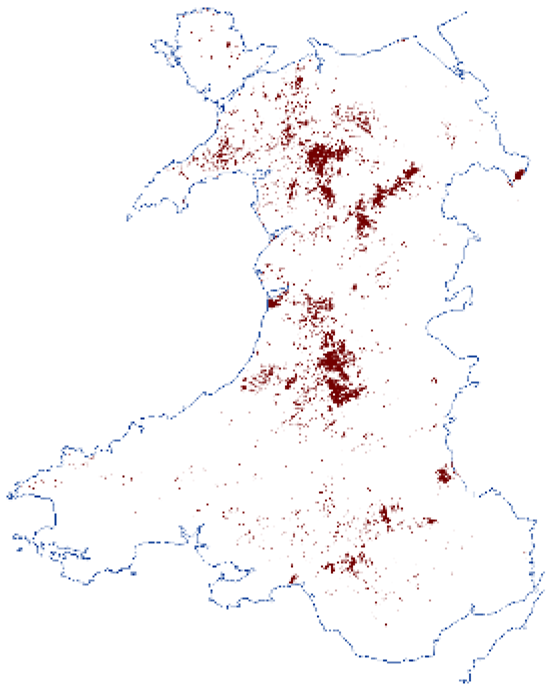

Figure 2.2.1.1 *A unified peat map for Wales, based on combined BGS and NRW data*

- Based on this new 'unified' Welsh peat map developed, peat soils are estimated to cover over 90,000 ha of Wales (4.3% of the total land area) of which 75% is in upland areas, and 25% in lowland areas
- Digital processing of aerial photographs suggests that there are at least 3,000 km of drainage ditches on peat soil in Wales
- Overall, around three quarters of the Welsh peat soil area is thought to have been impacted by one or more land-use activity, including drainage, overgrazing, conversion to grassland and afforestation with only 30% in 'good condition' with 25% 'modified' into grassland and 10% into woodland.
- As a result of these activities, Welsh peat soils are currently estimated to be generating 'anthropogenic' emissions of around 400 kt CO_2-equivalents per year (equating to around 7% of all Welsh transport-related emissions). This compares to an estimated natural 'reference' condition (i.e. if all the currently mapped peat area was natural bog or fen) of approximately 140 kt CO_2-eq yr^{-1} (Figure18).This indicates that natural peat soils are net emitters of greenhouse gas equivalents primarily due to the radiative power of methane. They store carbon overall if in good condition (or peat would not accumulate) and it is the protection of this carbon store and avoidance of emissions which is the objective Glastir can contribute to. As Glastir payments are targeted on semi-improved peats only, the potential emission reductions which could be achieved if all semi-improved peat soils could be returned to the reference state is estimated at 150 kt CO_2-eq yr^{-1}.
- Between 1990 and 2007 there was a decline in species richness in blanket bogs, but a slight increase in the number of characteristic ('positive indicator') bog species (positive CSM indicators).
- Fifty peat cores have now been collected from around Wales in order to measure how much CO_2 Welsh peats were able to sequester in the past, and how much this has been affected by recent agricultural management and forestry.

- Our recommendation is that these new findings should be used to revise the scheme as it goes forward to maximise benefits of Glastir payments for emission reduction from peat soils.

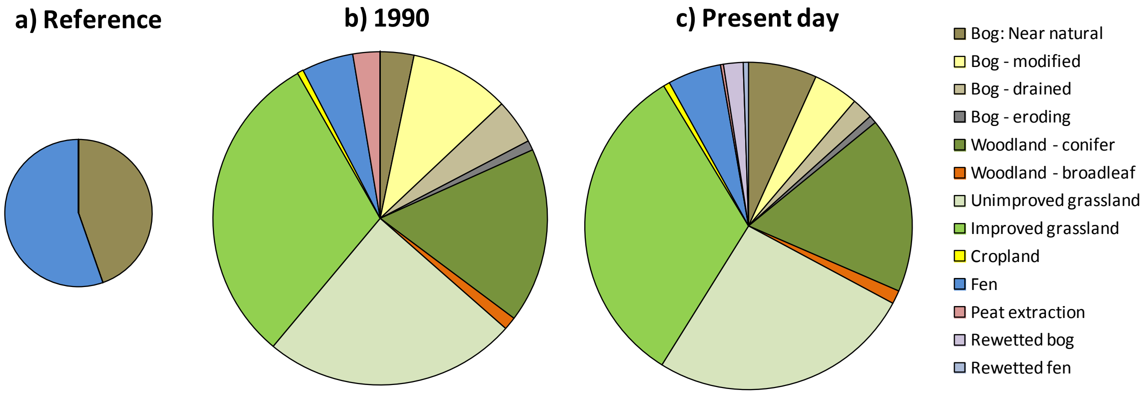

Figure 2.2.1.2 *The estimated contribution of different peat land-use/condition categories to total greenhouse gas emissions from Welsh peats under a natural 'reference' condition, in 1990, and at present day. The size of each pie chart is illustrative of the overall level of emissions.*

2.3 Methods

2.3.1 Peat extent and condition mapping

A new 'unified' peat map for Wales was generated by combining peat extent data from the British Geological Survey superficial geology map, together with Natural Resources Wales (NRW) data from: i) the Phase 1 Habitat Survey, where the vegetation present was strongly indicative of peat occurrence; ii) the Lowland Peat Survey; and iii) soil surveys undertaken by the former Forestry Commission Wales. The four datasets were combined into a single peat layer, with the presence of peat in any one of the four layers taken to indicate the presence of peat at that location. The condition of this peat area was then assessed using data from a number of sources. The NRW Phase 1 dataset provided the base vegetation layer, which was aggregated into a smaller number of broad categories (e.g. near-natural bog, modified bog, unimproved grassland, improved grassland) indicative of peat condition. In addition, aerial photography data (visible and near infra red) were obtained and analysed for a large part of the total peat area (approximately 75% of upland peats and 25% of lowland peats) in order to map the extent of drainage ditches. A linear feature extraction tool (PCI Geomatica LINE function) was used to identify areas containing drainage features, which were then manually digitised. The resulting drainage map was then overlaid on the land-cover map, and buffers were created around the ditches to represent the overall drainage-affected area within each land-use category (varying from 10m in upland blanket bog to 50 m in lowland fens and raised bogs). For peat areas under forestry (where ditches could not be mapped from aerial photography), as well as intensive grassland and arable land, we assumed that 100% of the area under that land-use was drained. For peat areas not covered by the air photos processed we assumed the same ditch density for unmapped areas as for mapped areas in the same land-use category. Finally, we produced initial maps and estimates of GHG emissions associated with each land-use/drainage class using Tier 2 'emission factors' (i.e. net GHG emissions in tonnes CO_2-equivalent per hectare per year) for each land-use class, derived from a combination of the IPCC Wetland Supplement (IPCC, 2013) and ongoing work for the UK Peatland Code (Smyth et al., 2014), following a method recently applied for Peat Soils GHG accounting for the UK Department of Energy and Climate Change (Evans et al., 2014)

2.3.2 Peat core carbon accumulation rates

Fifty peat cores were collected from four of the largest blanket bog areas in Wales; the Migneint and Berwyn areas in North Wales, and the Elenydd and Plynlimon in the Cambrian Mountains, South Wales. Intact 50 cm cores were collected from areas where land-management effects appeared minimal, and additional cores from areas affected by different management activities including drainage, grazing, burning and conifer afforestation. Cores were cut into thin layers, and the carbon content of each layer was measured. The layers were then dated using a combination of methods. For all cores, the number of Spherical Carbonaceous Particles (SCPs) in each layer were recorded; these are produced by coal burning power stations and the appearance and peaks of SCPs in the peat can be linked to fixed dates. A subset of cores were also analysed for levels of the radioactive isotopes of a range of metals including lead (which is produced by natural processes and provides an indication of peat age) and caesium (which peaked following the Chernobyl nuclear accident in 1986, and therefore provides a 'fixed date' in the record). Using these measurements, it was possible to calculate the rate of peat formation, and associated carbon accumulation, over the last century, and to examine who this has changed over time and in response to land-management activities.

2.4 Results

2.4.1 Where does peat occur in Wales?

The new unified peat map of Wales (Figure 2.4.1.1) highlights the geographical spread of Peat Soils across Wales. Although the largest concentrations of peat occur as blanket bog in the uplands of North and Central Wales, substantial areas of peat also occur in the uplands of South Wales, and in many more lowland areas such as Penllŷn, Anglesey, coastal Ceredigion, Pembrokeshire and Carmarthenshire. Overall, the area of peat in Wales is estimated at 90,200 ha, of which around 75% is found in the uplands (defined by NRW's 'Upland Boundary', based on habitat type) and 25% in the lowlands. As illustrated by Figure 2.4.1.1, a large part of the total peat area is located within relatively small units scattered across a wide area. This is significant, because smaller peat areas, particularly in the lowlands, are more susceptible to human modification through drainage and land-use change than larger upland blanket bogs, and are also more challenging to manage and monitor. In addition, previous assessments of peat extent in Wales (as well as the current Glastir target area for peat restoration) have largely been based on the Soil Survey of England and Wales (SSEW) 1:250,000 scale data from Cranfield University, which is at a coarser resolution than the new dataset, more reliant on landscape interpretation rather than ground survey, and which aggregates peat areas into larger aggregated 'soil associations' containing more than one soil type. This approach tends to increase the apparent area of peat in areas where it is the main soil type (e.g. upland blanket bogs containing smaller areas of other soils, which are mapped as a single 'peat' association) whereas it decreases the apparent area of peat in areas where it is a smaller component of the landscape (e.g. lowland areas where small areas of peat occur within larger areas of mineral soil). Whilst this approach provides a pragmatic means to represent heterogeneous soils at a broad spatial scale, it is prone to misinterpretation, and problematic for peat condition assessment because the location of peat units within larger soil associations is unknown, and land-use/condition data cannot therefore be overlaid. The new unified peat map should allow a more reliable assessment of the state of the Welsh peat resource as a whole, with better representation of lowland peats, and more accurate targeting of Glastir Peat Soils related options on those areas where peats are present. We recommend that the unified peat map should be used to derive a new target area for peat restoration, although (as with all maps) allowance should be made for uncertainties, and the presence or absence of peat at a specific location should be confirmed via ground-based survey before options are implemented.

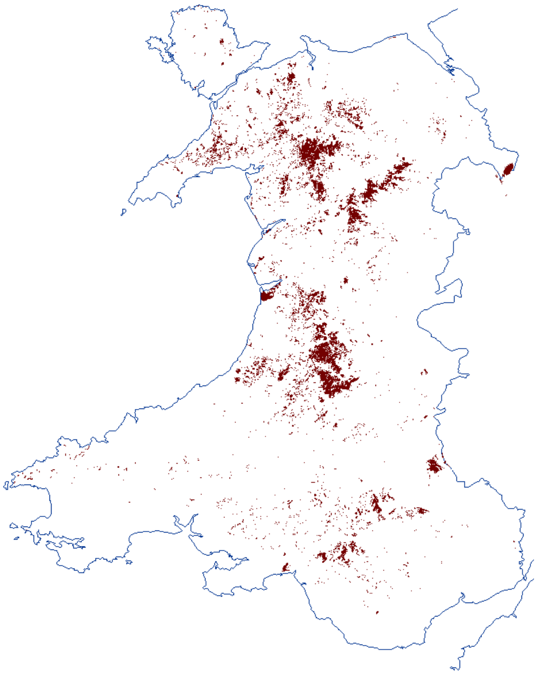

Figure 2.4.1.1 *A unified peat map for Wales, based on combined BGS and NRW data*

2.4.2. What are the current impacts of land-use on Welsh Peat Soils?

An initial classification of Welsh Peat Soils, based on the unified peat map and aggregated data from the NRW Phase 1 Habitat Survey, is shown in Table 2.4.2.1. This suggests that around 30% of the total peat area can be classified as 'good condition', around 90% of which is bog (mainly in the uplands), and the remainder fen (mainly in the lowlands). Although relatively small areas are defined as 'poor condition (e.g. eroding blanket bog), large areas of the total extent of both bog and fen are 'modified' (i.e. subject to vegetation changes such as encroachment of purple moor grass onto blanket bog, which may be linked to over-grazing), and other areas have been subject to conversion to heathland, grassland or woodland. Around a quarter of the overall peat area has been classified as grassland, with unimproved grassland prevalent in the uplands, and more intensive pasture types (improved, semi-improved and marshy grassland) having a disproportionately large impact on lowland peats. Overall, around half of all lowland peats are believed to be under grassland. On the other hand (and in contrast to areas such as East Anglia) the amount of arable land on peat in Wales is minimal. Just over 10% of Welsh Peat Soils are under woodland, of which the vast majority (> 90%) is under conifer, primarily large upland plantations. Scrub and broadleaf woodland on peat occur almost entirely in the lowlands, generally as small areas on the margins of lowland fens and raised bogs.

	Peat areas (ha)			*Area (%)*
Aggregated land cover	Upland	Lowland	Total	
Bog - good condition	22,324	1,683	24,007	*26.6%*
Bog - modified	19,438	2,094	21,532	*23.9%*
Bog - poor condition	221	5	226	*0.3%*
Fen - good condition	1,157	1,835	2,992	*3.3%*
Fen - modified	105	1,288	1,392	*1.5%*
Fen - poor condition	1	1	2	*0.0%*
Wet heath	1,978	391	2,369	*2.6%*
Dry heath	3,855	322	4,177	*4.6%*
Bracken	308	141	449	*0.5%*
Marshy grassland	3,569	3,563	7,132	*7.9%*
Unimproved grassland	6,758	490	7,247	*8.0%*
Semi-improved grassland	216	1,093	1,308	*1.4%*
Improved grassland	306	6,276	6,582	*7.3%*
Arable	1	101	102	*0.1%*
Scrub and broadleaf	26	920	946	*1.0%*
Conifer	6,892	1,682	8,574	*9.5%*
Other	540	658	1,198	*1.3%*
Total	*67,695*	*22,540*	*90,235*	

Table 2.4.2.1 *Aggregated peat land-use and condition classification for Welsh peats, aggregated from NRW Phase 1 data for Wales overlaid on the unified peat map, and subdivided into upland and lowland areas based on the NRW Upland Boundary.*

2.4.3. How much of the Welsh Peat Soils area has been affected by drainage?

Drainage of Peat Soils occurred during the 19th and 20th centuries, with the aim of changing the natural vegetation cover (e.g. to increase grass cover to support grazing in the uplands, or as part of grouse moor management) or as part of land-use changes such as conversion to intensive grassland or forestry plantation. However, draining Peat Soils exposes previously waterlogged peat to oxygen, increasing decomposition rates and potentially causing the Peat Soils to switch from a CO_2 sink to a CO_2 source. Although drainage is known to have been extensive in Wales, until now no detailed, national-scale information has been available. Based on the aerial photograph analysis undertaken for GMEP, we now have detailed maps of drainage extent and intensity for the majority of the Welsh Peat Soils area. Figure 2.4.3.1 shows an example of the extent of drainage ditches at the Cors Fochno raised bog, adjacent to the Dyfi estuary, with a range of buffer distances around each digitised ditch illustrating the potential impact on the overall peat area.

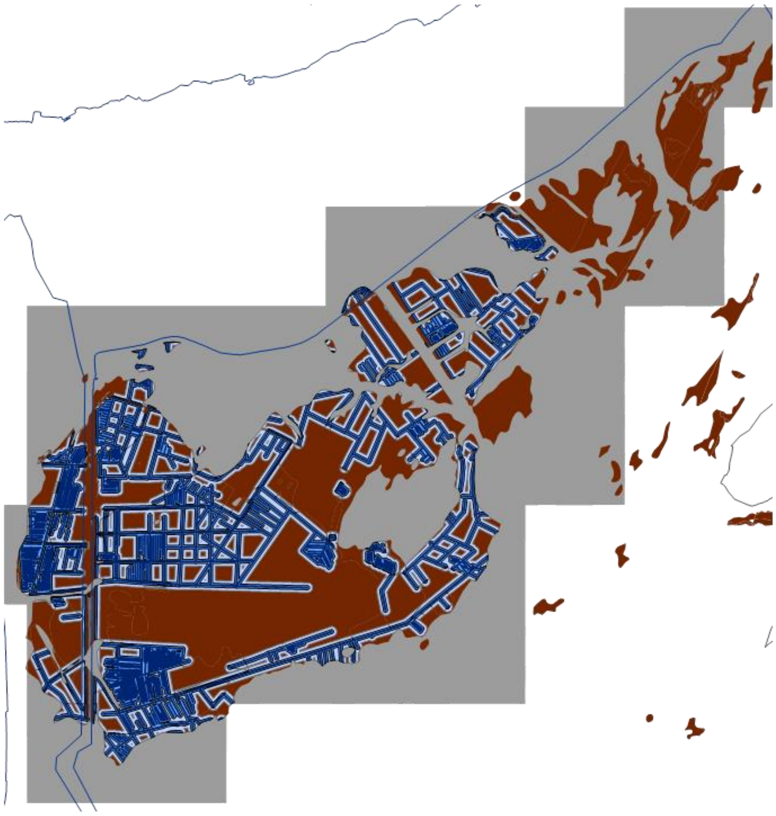

Figure 2.4.3.1 *Example ditch map for the Cors Fochno lowland raised bog complex, Dyfi estuary. The brown area shows the extent of Peat Soils, grey 'tiles' show areas within which ditches have been digitised from aerial photographs, and blue shading shows a range of buffer distances (i.e. assumed drainage impacts) around each ditch, from 10 m (dark blue) to 50 m (light blue).*

Overall, air photos capturing 73% of the upland peat area and 29% of the lowland peat area were processed. Within this area, a total of 1,810 km of ditches were digitised (1,502 km in the uplands and 209 km in the lowlands). It should be noted that the extraction of ditch features from air photos is subject to an inevitable degree of error (e.g. where ditches are not visible below vegetation canopies, or where other linear features such as paths or walls are mis-categorised). However, comparison of digitised ditch layers with NRW ground surveys showed generally good correspondence. It is also worth noting that a considerable length of ditches (1,334) was mapped in areas not classified as peat, indicating that drainage has also significantly affected other soil types, such as peaty gleys.

2.4.4. How much CO_2 can a blanket bog sequester?

In the past, peat formation processes sequestered CO_2 from the atmosphere and locked it up into the soil, which had a cooling effect on the earth's climate. In some areas this process continues, whilst in others it has been reduced or even reversed due to land-management, potentially leading to the emission to the atmosphere of carbon that has been stored for thousands of years. For the range of Welsh blanket bogs over which cores have been collected, the results suggest that in the 19th century these sites were accumulating in the region of 1.5 tonnes of CO_2 per hectare per year through the active formation of new peat. Since that time, many Welsh Peat Soils have been subject to land-use changes such as ditching, afforestation, intensification of grazing and managed burning for red grouse, which have either reduced the cover of peat-forming plant species such as *Sphagnum* mosses, or lowered the water table in the (naturally waterlogged) peat, allowing it to decompose more rapidly.

Preliminary results (Figure 2.4.4.1) suggest that some of these management activities have had a significant effect on rates of peat CO_2 sequestration. In particular, carbon accumulation rates in areas affected by drainage appear to have declined sharply, suggesting that these areas are less able to sequester CO_2 from the atmosphere than before, and could now be sources of CO_2 to the atmosphere. It appears that afforestation may have increased the amount of carbon being added to the peat surface as forest needles, whilst also causing a loss older carbon from the peat itself as drainage ditches have lowered water tables and allowed decomposition rates to increase. Work on these data is ongoing, with the aim of producing new estimates of the overall carbon balance of Welsh blanket bogs under different land-management in order to provide a better understanding of the benefits of Glastir options for soil carbon sequestration, and to improve national-scale greenhouse gas accounting.

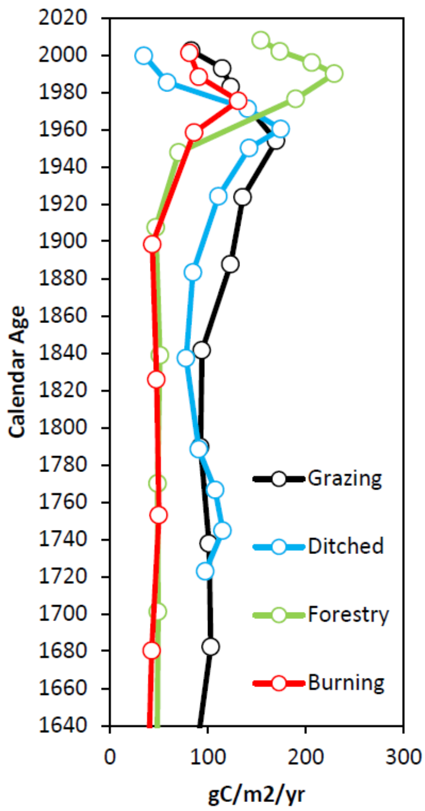

Figure 2.4.4.1 *Average measured rates of carbon accumulation over time for peat cores collected from Welsh blanket bogs under different land-management types. Note that, in a natural system, the 'apparent' rate of carbon accumulation should increase towards the surface, because the recently-formed material near the surface has had less time to decompose than peat which was formed longer ago.*

2.4.5. What is the current contribution of Welsh Peat Soils to greenhouse gas emissions?

Using the spatial data collated for GMEP as described above, together with 'emission factors' developed under other projects, we have been able to generate the first, national-scale maps of greenhouse gas (GHG) emissions from Peat Soils anywhere in the UK. An example emissions map is shown for the Cors Fochno raised bog complex in Figure 2.4.4.1 This shows low emissions from the surviving area of semi-natural bog vegetation in the southwest part of the peat area, with higher emissions where this is intersected by drainage ditches. Wooded areas are associated with higher emissions from the peat (the map does not take account of CO2 uptake into tree biomass), whilst areas of drained and improved grassland around the fringes of the raised bog have high GHG emissions. Note that even areas of intact raised bog are estimated to be small net GHG emissions sources, due to emissions of methane, a powerful greenhouse gas, from the wet peat. However, because these areas of intact Peat Soils vegetation are continuing to sequester CO2 through peat formation they make a make a much smaller contribution to GHG emissions than drained and modified Peat Soils, and will have a net cooling effect on the climate over longer time periods.

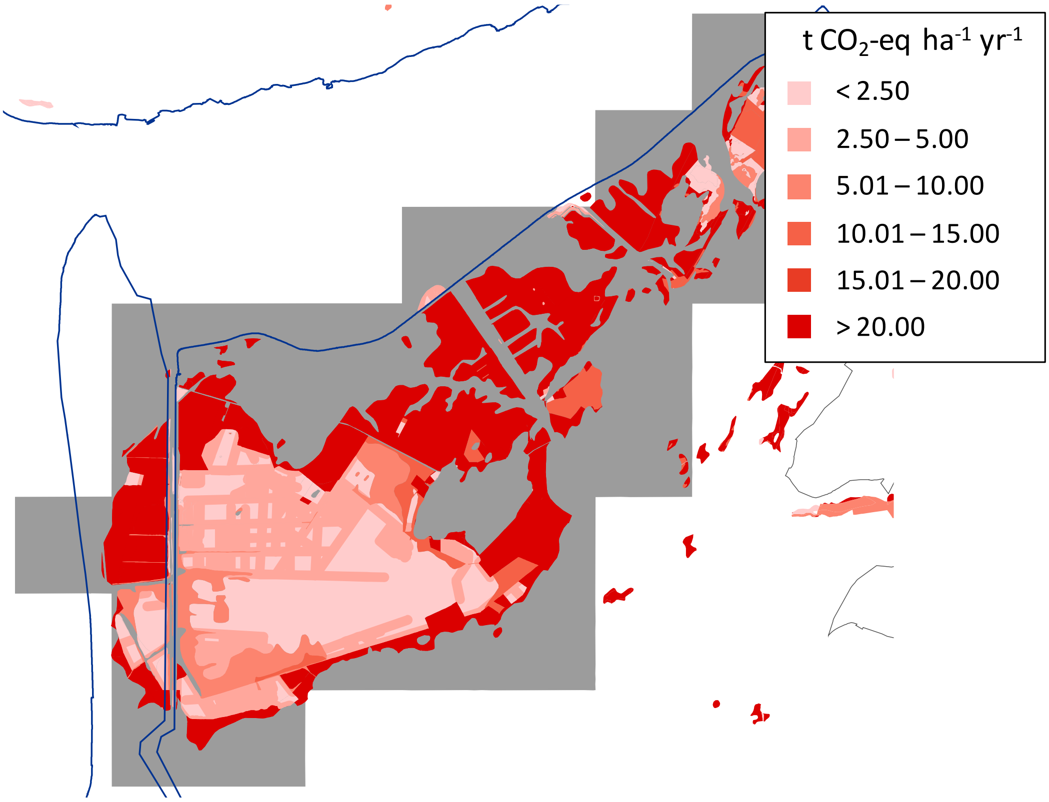

Figure 2.4.5.1 *Example of estimated greenhouse gas emissions for the Cors Fochno, based on the unified peat map, Phase 1 land-cover categories and digitised ditch map. Grey 'tiles' show areas within which ditches have been digitised from aerial photographs.*

Scaling this analysis up to the full Peat Soils area, as defined by the unified peat map, suggests that total GHG emissions from Welsh Peat Soils are currently in the region of 550 kt CO_2-eq yr^{-1}. Of this total emission, 59% is associated with CO_2 emissions (including 'indirect' emissions from dissolved and particulate organic carbon), most of which is derived from drained areas. Around 37% of the total GHG emissions are in the form of CH_4, mainly from undrained and re-wetted bogs and fens (which are therefore mainly of natural rather than anthropogenic origin) with the remaining 4% as N_2O, primarily from improved grasslands. This present-day emission compares to estimated natural emissions from Welsh Peat Soils (i.e. is all the currently mapped peat area was natural bog or fen) of approximately 140 kt CO_2-eq yr^{-1}, which represents the balance of natural CO_2 sequestration and natural CH_4 emissions. The present-day estimate takes account of the estimated changes in emissions that have occurred since 1990 as a result of drain-blocking restoration work that has taken place (primarily on upland blanket bogs) during this time, and of the area of upland bog that was subject to grazing reductions under Tir Gofal. This assessment, which was made as part of an initial assessment of Welsh GHG emissions for the Department of Energy and Climate Change (Evans et al., 2014) assumes that all peat re-wetting projects were effective, and that the grazing options implemented under Tir Gofal were sufficient to convert blanket bog from 'modified' to 'near-natural' status. Based on results from GMEP, it should be possible to test these assumptions in future. Comparing estimated present-day emissions to natural 'reference' emissions suggests a maximum climate mitigation potential (if all Welsh Peat Soils were returned to near-natural condition) of around 300 kt CO_2-eq yr^{-1}.

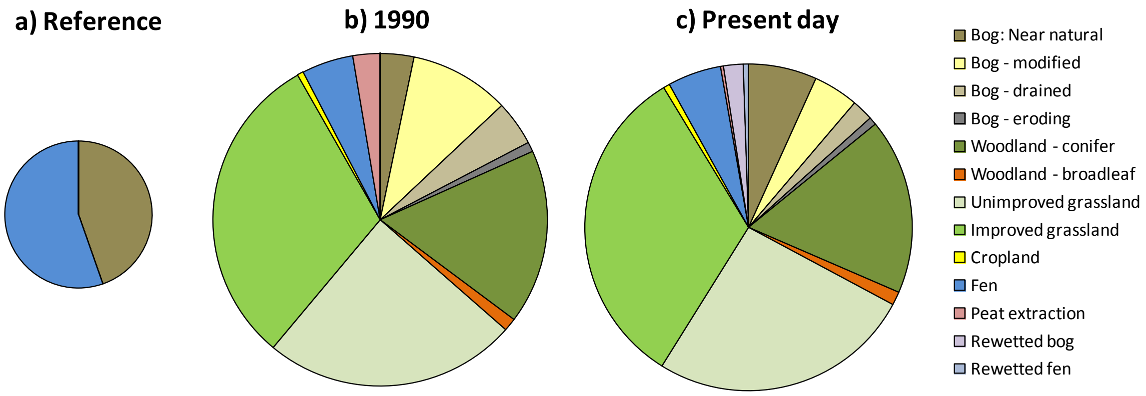

Figure 2.4.5.2 *The estimated contribution of different peat land-use/condition categories to total greenhouse gas emissions from Welsh peats under a natural 'reference' condition, in 1990, and at present day. The size of each pie chart is illustrative of the overall level of emissions.*

Figure 2.4.5.2 illustrates the contribution of different land-use/peat condition categories to total emissions. For Welsh Peat Soils as a whole, the main sources of GHG emissions are believed to be improved and unimproved grassland on peat (58% of all emissions), followed by conifer plantations (17%). Drained, modified and eroding bogs are estimated to have contributed around 15% of GHG emissions in 1990, reducing to around 7% at the present time as a result of restoration and agri-environment options. However it is important to note that the latter figure carries a large uncertainty as it assumes a high success rate for the restoration options undertaken, which may not have been achieved in reality. However, it does make allowance for the likelihood that re-wetted bogs may emit slightly more CH_4 and sequester slightly less CO_2 than natural bogs, at least in the initial post-restoration period. Furthermore, it is worth noting that gains achieved through grazing options may be delayed due to lags in ecosystem recovery, or temporary if grazing controls are not maintained under subsequent agri-environment schemes.

Finally, it is worth noting that the total anthropogenic emissions derived from this assessment (and hence the maximum future climate mitigation potential) are somewhat larger than previous estimates that have been made using a similar methodology, but less detailed spatial data (ADAS, 2014; Evans et al., 2014). The main differences arise from the use of NRW Phase 1 data in this assessment, rather than the CEH Land Cover Map 2007 (which gave a smaller area of grassland on peat) in the previous assessments, and also the absence of detailed data on drainage ditch extent in the previous analyses. Considerable uncertainty still remains in the current assessment, however, particularly in relation to the quantification of emissions from grassland, modified bog and drained fen, which are all currently based on very limited field emissions measurements, in some cases from quite dissimilar habitats such as drained grasslands in the Netherlands and Germany. New data based on UK measurements will be used to revise the current emission factors used in the assessment, and therefore the overall emissions estimates.

2.5 Future plans

The peat condition assessment work for GMEP is ongoing, and should lead to further improvements in the mapping of Welsh Peat Soils in future. Specifically, aerial photographs are currently being used to remotely map peat vegetation, in particular the extent of purple moor grass (*Molinia caerulea*) on blanket bogs, which has a detrimental impact on habitat condition and may contribute to increased GHG emissions. The analysis of peat core data will continue during Year 3 of GMEP, with the aim of quantifying rates of carbon accumulation in blanket bog in relation to its management. By relating historical rates of peat accumulation to the vegetation community, we aim to develop a method that will allow data collected during GMEP vegetation surveys to be used to estimate rates of current carbon accumulation, and therefore to monitor changes in Peat Soils carbon sequestration over time in response to Glastir options. These results should also (along with new flux measurements being made in other ongoing projects) enable us to refine the current emission factors for a range of peat condition categories, and subsequently to refine the emissions maps and national estimates described above.

In addition, the peat condition assessment being undertaken for GMEP is contributing directly to an ongoing UK-wide project, funded by the Department of Energy and Climate Change, to develop methods to account for GHG emissions from Peat Soils and other wetlands across the UK. This should ultimately enable Peat Soils emissions to be included in national greenhouse gas accounts, and in reporting to international frameworks such as the Kyoto Protocol. The work is also supporting the UK Peatland Code, a 'Payment for Ecosystem Services' scheme designed to facilitate investment in peat restoration by recognising and quantifying the climate mitigation benefits this delivers. By quantifying these benefits, it should be possible to develop and target future Glastir options in order to optimise the use of resources, and to maximise the climate mitigation benefits that can be delivered through the scheme.